Protocols for Projects for Simulation of Present and Future Climates in California

Philip B. Duffy, John A. Taylor, Karl E. Taylor
Lawrence Livermore National Laboratory

Table of Contents

D R A F T

Introduction

Strategic goals

• Provide planning agencies, impacts researchers, and policymakers with the highest quality information on climate change in California;
• generate climate scenarios that will become the standard scenarios for climate change planning in the State government;
• generate climate scenarios with enough temporal and geographic resolution to allow advanced climate change impact studies;
• provide researchers with a detailed analysis of how well their models reproduce observations, both in absolute terms and relative to other models, with the goal of developing better climate models;
• coordinate to the maximum extent possible with related efforts (NARCCAP, OURANOS, etc) in order to avoid duplication of effort and ensure the maximum possible involvment by other researchers; and
• maximize return on sponsor's investment by facilitating analysis of simulations and relevant observations by researchers funded by others.

Technical goals

• Evaluate the ability of regional climate models (RCMs) and statistical downscaling techniques to reproduce observations of California's climate. Assess the strengths and weaknesses of individual dynamical and statistical models, as well as the overall relative merits of dynamical vs. statistical approaches to downscaling;

• make results of above model evaluation exercises available to researchers, and publicly;

• make probabilistic projections (i.e. including uncertainties) of future climate in California. These comparisons will be based on all participating groups simulating one or more common climate-change scenarios, using identical boundary conditions for each scenario.

• assess to what extent these uncertainties can be narrowed by developing an optimal weighting strategy that gives more weight to models which more accurately reproduce observations;

• convert all simulation results into a common file format, to facilitate analysis by independent researchers and by policymakers; this an is important way to maximize return on the sponsor's investment.

• make results of all simulations, and appropriate documentation, publicly available via the internet, again to facilitate analysis by the broader communities of climate researchers, impacts assessors, and decision-makers.

Study area/model domain, and model resolution

The area of interest to the sponsor (PIER/CEC) is the state of California. The area of analysis will include the Pacific Northwest (because this region supplies hydropower to California), the Colorado River Basin (which supplies water to California) and parts of Nevada that supply water to California. The simulation domain for regional climate models (RCMs) will include these regions. All participating RCM groups will use the same model domain; this will simplify interpretation of results by eliminating one unnecessary difference between different modeling groups.

Because impacts of climate change on California's hydrological cycle are potentially important, the CEC expects that simulations will be performed at sufficient spatial resolution to accurately simulate the hydrological cycle. Because mountain snow cover is an essential part of the hydrological cycle in California, this means that spatial resolutions sufficient to accurately represent the water content of mountain snow should be used. Recent research has shown that resolutions in the neighborhood of 40 km are not adequate for this purpose (Duffy et al. 2004). Thus, the CEC's goal is for RCM groups to use 10 km resolution in California with coarser resolution, if needed, outside of California. In addition, some impacts studies involving e.g. ecological dynamic models require "transient" simulations in which climate evolves continuously from the present. In recognition of the great computational demands this imposes, the CEC expects the lead contractor to provide participating RCM groups with at least some of the supercomputing resources needed to perform required simulations.

Multiple projects and funding options

Below we describe separate projects dealing with (1) evaluation of ability of RCMs and statistical downscaling methods to represent the present climate in California (i.e. a model evaluation project); (2) use of same models and statistical downscaling techniques to make probabilistic projections of future climate. For the model evaluation (present-climate) project, we present plans for three project options, having total CEC funding levels of \$500K, \$1M, and \$2M. For the project on projection of future climate, we present one option with a total budget of \$2M.

Coordination

Coordination between related projects maximizes return on sponsors' investments, by eliminating duplication of effort and maximizing inter-comparability of results across different projects. CEC-funded modeling studies of California will be coordinated with ongoing related projects, especially the North American Regional Climate Change Assessment Program (NARCCAP; under the direction of L. Mearns at NCAR) and the OURANOS consortium in Canada (D. Caya, Director). The exact form of coordination is still to be determined, but may include use of the same climate change scenarios and time slices; and use of the same GCMs as starting point for downscaling. In addition, CEC's California studies could use as a starting point for downscaling simulations performed at

~50 km resolution for NARCCAP or OURANOS. This would allow the CEC to leverage results of and investments in these other projects, and use of the same scenarios and GCMs would be automatic.

Project organization

Hub and spoke structure

The project will be coordinated at a "hub" location, whose responsibilities will include

• interacting with the sponsor (CEC);
• ensuring that project deliverables are completed on time;
• providing input (e.g. boundary condition) data to participating groups;
• providing some computer access to participating groups;
• assembling observational data needed for evaluation of simulations;
• developing techniques and metrics for evaluation of simulations;
• performing some analysis of simulation results;
• providing participating groups with tools for performing quality control on simulation results, and for converting simulation results into a common file format;
• assembling documentation on models and downscaling techniques used;
• making simulation results and documentation publicly available.

Participating ("spoke") simulation groups will be responsible for

• providing computer time to perform required simulations (in some cases)
• performing agreed-upon simulations on time;
• performing quality control on simulation results (using tools supplied by the hub);
• converting simulation results into a common file format (using tools supplied by the hub);
• providing appropriate documentation for their simulations.

Funding of participating modeling groups

Groups participating in global model intercomparison projects (e.g. AMIP, CMIP, PMIP) have traditionally not been compensated for the cost of performing and submitting simulations. In some cases, however, free computer access was provided. This philosophy, including supplying computer time, is followed in the Low Cost model evaluation project described below. In the higher-cost projects, however, the workload for participating RCM groups will be much greater, because of the larger number of simulations required. (This is quantified in Appendix 1. The statistical downscaling work does not present the same problem because of the relatively low computational burden afforded by this technique.) To prevent lack of support from being a barrier to participation, and to help ensure that results are provided in a timely manner, we therefore recommend at least partial support for effort costs of a limited number of selected dynamical and statistical downscaling groups in these higher-cost projects. Groups to be funded will be selected by the Hub contractor, with final approval from the

CEC. Any dynamical or statistical downscaling groups willing to participate *gratis* will be encouraged to do so.

Computer access:

As discussed above, the CEC's goal is for RCM simulations for this project to be performed at 10 km resolution. (Resolution in this ballpark is needed to accurately represent the hydrological cycle in California.) This requirement creates very significant computational demands for participating RCM groups. To help meet these requirements, the Hub contractor will provide participating groups with limited access to a large, shared computer. (This was done in the initial stage of the AMIP project.) This will have the additional benefit of concentrating the large volume of model output in one location, and thus minimizing the need to move large quantities of data. For the higher-cost model intercomparison projects, the cumulative computational needs of all participating groups will probably exceed what any Hub contractor can provide. Therefore for these project options, participating groups will be expected to supply their own computing to the maximum extent possible, and will be expected to demonstrate ability to do this before receiving funding from the CEC.

Selection of the Hub Contractor

The Hub Contractor for the intercomparison work will be selected using a competitive process. PIER/CEC will invite known Centers of Excellence on this type of work to submit proposals to implement the final Protocol. The selection will be made based on the technical merits of the proposal and the amount of matching funds provided. The matching funds can be in the form of computer resources and/or software that will lower the overall cost of the project or allow for additional work, and availability of senior technical personnel.

The Hub contractor will be sought once a final protocol is available and once the PIER RD&D Committee, which is formed by two Commissioners, makes a decision about the PIER level of funding.

Relevant PIER/CEC funded activities

PIER/CEC is investing significant resources in research activities at the Scripps Institution of Oceanography (SIO) that can be described in general terms as climate monitoring, analysis, and modeling. SIO and the Desert Research Institute (DRI) are installing meteorological and hydrological stations in remote high elevations and in important transects in the state. The data, however, may not be ready for this intercomparison work, but it will be useful for future intercomparisons to be conducted in about six years. The climate analysis work being done by SIO could guide the effort designed to select the global climate models best-suited for the California region. For example, there may be little hope for global models that do not properly capture historical El Niño events (in the statistical sense) because of the importance of this mode of variability for California (Wigley 2004).

SIO and the Western Regional Climate Center (WRCC) have developed a California Climate Data Archive website (http://www.calclim.dri.edu) that eventually will make long-term climate data easily available to state agencies, utilities, and researchers. This effort should facilitate the preparation of historical gridded data for comparison with dynamic model outputs or specific stations for statistical models.

Under funding from PIER, SIO is also evaluating and enhancing their dynamic and statistical downscaling techniques. Regarding dynamical modeling, SIO is using the Regional Spectral Model (RSM) at 10 km resolution for a climate re-analysis of the U.S. and California regions for the last 50 years. In the near future SIO will investigate the effects on climate of changes of vegetation and of land use changes (e.g., increased urbanization) in California again simulating conditions in the last 50 years. With respect to statistical techniques, SIO is enhancing a weather generator and a canonical correlation method to allow for statistical downscaling of GCM outputs (Gershunov and Cayan 2003). These methods will allow the efficient and low-cost downscaling to numerous GCM outputs as suggested by Tom Wigley in a discussion paper prepared for PIER (Wigley, 2004).

SIO is also calibrating/enhancing a statewide hydrological model that will be used to generate the hydrological outputs needed to drive the water system models being enhanced under separate funding for PIER.

Ben Santer, Tom Wigley, and Phil Duffy are under contract with PIER to conduct a preliminary climate change detection and attribution study for the California region. This study may prove useful to the intercomparison effort.

Mark Jacobson from Stanford is conducting an exploratory study of the role of aerosols on climate in California. Results of this study will be available by October 2004. Similarly, Daniel Rosenfeld and his team from the Hebrew University of Jerusalem are investigating the role of aerosols on precipitation levels in high elevation in California, because their preliminary analysis suggests that aerosols may be diminishing the precipitation enhancing orographic effect in the state.

Finally, PIER is providing very limited support to dynamic regional climate modeling groups in UC Santa Cruz (Lisa Sloan), UC Davis (Bryan Weare), and Lawrence Berkeley National Laboratory (Norm Miller).

Low-cost ($500K) model evaluation project

Project scope

This minimum-cost project option will focus on evaluation and intercomparison of statistical and dynamical downscaling approaches as applied to California. To most clearly identify the strengths and weaknesses in the competing downscaled solutions, an observationally-based large-scale solution will be used as the starting point for downscaling. (This will minimize the extent to which defects in the large-scale solution—e.g. in lateral boundary conditions supplied to RCMs—create errors in the downscaled solutions which could be misattributed to the downscaling methodologies themselves.) Thus, this project will use an atmospheric "reanalysis" (a model product created by assimilating the maximum possible number of observations into a climate model) as the starting point for downscaling. Simulations from (free-running) global climate models (GCMs) will not be downscaled in this project option.

Technical Approach

As explained above, this project will evaluate how well different downscaling approaches and models can reproduce the present climate in California. The starting point for downscaling will be the ECMWF's "ERA 40" reanalysis. This choice of reanalysis is dictated by the CEC's desire for dynamical models to simulate California on a 10 km grid. (Spatial resolution in this ballpark is needed to adequately simulate California's hydrological cycle.) Bertrand Denis et al. (2002) showed that problems result if the resolution "jump" (ratio of grid sizes) between the driving and nested models is much greater than around 12. Thus, if we wish nested models to use 10 km resolution, the grid size in the driving large-scale solution (in this case reanalysis) should not greatly exceed 120 km. This rules out the use of traditional coarse-resolution reanalyses, and suggests that the ERA 40 reanalysis, at T159 truncation (~125 km resolution), might be well-suited for our purpose.

To meet budget constraints, this project option will not develop new evaluation methodologies, or new software tools for model evaluation. Again to meet budget constraints, this option will explicitly pay for only minimal analysis of simulation results. To maximize return on the sponsor's investment, analysis by third parties will be facilitated by converting all model results to a common file format, and by making all model results and appropriate documentation publicly available.

Specific tasks

- Prepare and distribute input data for downscaling (atmospheric reanalysis, etc.) to participating downscaling groups (Hub)
- Simulate the present climate in California by downscaling from reanalysis (Spokes)
- Put downscaling results into a common file format (Hub)
- Gather relevant observational data. (Hub)
- Perform basic evaluation of downscaling results vs. observations and reanalysis (Hub).
- Make downscaling results, appropriate documentation, relevant observational data (or links thereto), and evaluation results publicly available (Hub)

Roles and Responsibilities

Senior staff at the Hub location will be responsible for

• overall project coordination;
• interactions with the sponsor (CEC) and with Spoke participants;
• meeting reporting obligations to the sponsor (e.g. reports and meetings);
• determine appropriate methods for evaluating downscaled solutions; and
• coordination of a peer-reviewed publication.

Technical staff at the Hub location will

• prepare input data (reanalysis etc.) and distribute them to Spoke participants;
• prepare software for conversion of simulation results to a common file format;
• converting results of downscaling into a common file format;
• gather observational data for evaluation of downscaled solutions;
• perform evaluation of downscaled solutions; and
• establish project web site that will make simulation results, documentation, relevant observational data, results of simulation evaluations publicly available.

Staff at Spoke locations will be responsible for

• producing a downscaled version of present climate in California using large-scale input data provided by Hub; and
• contributing to a peer-reviewed publication.

The tables below list effort levels and costs associated with each project task. For purposes of estimating costs, effort costs are assumed to be $200K/yr for senior staff and $150K/yr for technical staff. These effort breakdowns, cost rates, and project budgets are not meant to be rigidly adhered to; rather, they are shown to provide some reassurance that the project's scope of work is appropriate to the overall funding available.

	Year 1	Year 2
Hub	Prepare and distribute large-scale solution (reanalysis) Gather observational data for evaluation	Evaluate downscaling results by comparing to observations. Make all downscaling results publicly available.
Spokes	Simulate present climate in CA by downscaling reanalysis	Put downscaling results into standard file format.

Table 1: Outline of tasks to be performed at Hub and Spoke locations.

	Task	Effort level senior staff (mos)	Effort level technical staff (mos)	Est'd Cost (Year 1; $K)
Hub	Prepare and distribute large-scale solution (reanalysis)		2	$25
	Gather observational data for evaluation	0.5	2	$33
	Develop software for conversion of simulation results to common file format		1	$13
	Project coordination; interaction w/ sponsor, etc.	2		$33
Total Hub		2.5	5	$104
Each Spoke	Simulate present climate in CA by downscaling reanalysis	0		$0
Total each Spoke		0	0	$0
Total all Spokes		0	0	0
Total Hub + Spokes		**2.5**	**5**	**$104**

Table 2: Detailed effort breakdown for Year 1 of Low-Cost model evaluation project. Effort costs are assumed to be $200K/yr for senior staff and $150K/yr for technical staff. Table shows effort levels and costs for each spoke location; bottom rows shows total costs assuming there are 3 spoke locations.

	Task	Effort level senior staff (mos)	Effort Level technical staff (mos)	Est'd Cost (Year 2; $K)
Hub	Evaluate downscaling results vs. observations and reanalysis		6	$75
	Establish project web site.	1.5	1.5	$44
	Preparation of peer-reviewed publication	2	1	$46
	Put downscaling results into standard file format.		0.5	$3
Total Hub		3.5	8.75	$168
Spokes	Preparation of peer-reviewed publication	1	1	$29
Total each spoke		1	1	$29
Total all Spokes		3	3	87.5
Total Hub + Spokes		6.5	11.75	**$255**

Table 3: Detailed effort breakdown for Year 2 of Low Cost model evaluation project. Effort costs are assumed to be $200K/yr for senior staff and $150K/yr for technical staff. Table shows effort levels and costs for each spoke location; bottom rows shows total costs assuming there are 3 spoke locations.

	Year 1	Year 2	Total
Effort at Hub	$104	$168	$272
Effort at all Spokes	$0	$88	$88
Computer access	$40	$40	$80
Data storage	$4		$4
Travel/workshops	$20	$20	$40
Publications		$20	$20
Total	**$168**	**$335**	**$503**

Table 4: Estimated overall project budget for Low Cost model evaluation project.

Intermediate-cost ($1000K) model evaluation project

Project scope

This option includes everything in the Low-Cost Option, as well as

(1) downscaling the solutions of two (free-running) global climate models, in addition to downscaling reanalysis. This will allow us to understand how well downscaling methods can reproduce the present climate when starting from large-scale solutions that may contain significant errors. The two GCMs will be selected from among those that have performed IPCC scenario simulations with 6-hourly output saved. In addition, the two GCMs should have significantly different responses to climate change within the study area.
(2) Additional analysis activities: development and application of new metrics (figures of merit) and tools for evaluation of high-resolution regional simulations (as distinct from approaches commonly used to evaluate coarse-resolution global simulations). Along with simulation results and observations, these tools will be made publicly available to facilitate analysis of project results by third parties.

Specific tasks

This option will include all tasks from the Low-Cost Option, plus

• simulation of present-climate in California by downscaling present-climate-simulations from two GCMs (Spokes);
• Additional evaluation of present climate simulations, including evaluation of ability to simulate variability on a range of time scales (Hub).

	Task	Effort level senior staff (mos)	Effort level technical staff (mos)	Est'd Cost (Year 1; $K)
Hub	Prepare and distribute large-scale solution (reanalysis +2 GCMs)		3	$38
	Gather observational data for evaluation	0.5	2	$33
	Develop software for conversion of simulation results to common file format		1	$13
	Project coordination; interaction w/ sponsor, etc.	4		$67
Total Hub		4.5	6	$150
Each Spoke	Simulate present climate in CA by downscaling reanalysis + 2 GCMs	1	3	$54

Total each Spoke		1	3	$54
Total all spokes		5	15	$271
Total Hub + Spokes		9.5	21	$313

Table 6: Detailed effort breakdown for Year 1 of Intermediate-Cost model evaluation project. Effort costs are assumed to be $200K/yr for senior staff and $150K/yr for technical staff. Table shows effort levels and costs for each spoke location; bottom rows shows total costs assuming there are 5 spoke locations.

	Task	Effort level senior staff (mos)	Effort Level technical staff (mos)	Est'd Cost (Year 2; $K)
Hub	Evaluate downscaling results vs. observations.	2	12	$183
	Establish project web site.	2	3	$71
	Preparation of peer-reviewed publication	3	2	$75
	Put downscaling results into standard file format.		1	$13
Total Hub		7	18	$342
Spokes	Preparation of peer-reviewed publication	1	1	$29
Total each spoke		1	1	$29
Total all Spokes		5	5	$146
Total Hub + Spokes		12	23	$429

Table 7: Detailed effort breakdown for Year 2 of Intermediate-Cost model evaluation project. Table shows effort levels and costs for each spoke location; bottom rows shows total costs assuming there are 5 spoke locations.

	Year 1	Year 2	Total
Effort at Hub	$150	$342	$492
Effort at all Spokes	$271	$146	$417
Computer access	$35		$35
Data storage	$35		$35
Travel/workshops	$20	$20	$40
Publications		$20	$20
Total	**$203**	**$285**	**$1,038**

Table 8: Estimated overall project budget for Intermediate Cost model evaluation project.

High-cost ($2000K) model evaluation project

Project scope

This option will provide the most comprehensive evaluation of techniques for simulating California's climate. This option will include everything in the Intermediate-cost project, with additional research activities such as those listed below. Research activities may include a special focus on the hydrological cycle. Each of these activities will be performed by the Hub contractor and one or more selected Spokes, with the intention that each Spoke will participate in at least one activity.

Sensitivity to spatial resolution of large-scale solution: The sensitivity to spatial resolution of the large-scale driving solution will be investigated. There are two possible ways to do this: (1) use boundary conditions from a GCM run at multiple resolutions (here the finer resolution solutions should be more accurate on the large scale, as well as more detailed); or (2) use boundary conditions at different resolutions created by low-pass filtering one fine-resolution solution (here the finer-resolution solutions will be more detailed, but not more accurate on the large scale, than the coarse-resolution solutions.)

Effect of spatial resolution of regional climate model: The effects of increased RCM resolution on the realism of downscaled present-climate simulations will be investigated. Evaluation will include variables relevant to the hydrological cycle.

Regional vs. global reanalysis: Relative realism of downscaled solutions using global vs. regional reanalysis will be investigated. This further evaluates effects of resolution of global model output on realism of downscaled solutions.

Dynamical vs. statistical downscaling: The ability of statistical vs. dynamical downscaling approaches to simulate the present climate in California will be explicitly analyzed. Competing downscaling approaches will start from the same large-scale solution (coarsened reanalysis).

Expanded web portal: The web site will be expanded with the goal of becoming the 'portal' for facilitating the analysis of climate change on California, including in additional to data and analysis tools a comprehensive set of links to climate change information about California.

Besides including the above research activities, this project option will include downscaling of one additional GCM. Thus, the first year's activities will include downscaling of 1 reanalysis and 3 GCMs.

This project's budget will also permit a more systematically-determined choice of GCMs to be downscaled. Criteria for selecting GCMs may include

• ability to realistically simulate ENSO;
• no flux adjustments;
• realistic on-shore moisture fluxes from the Pacific ocean;
• Adequate simulation of anthropogenic warming of Pacific Ocean;
• realistic simulation of 20th-century trends in the Western U.S.
• realistic treatment of aerosols.

	Task	Effort level senior staff (mos)	Effort level technical staff (mos)	Est'd Cost (Year 1; $K)
Hub	select GCMs to be downscaled	2	2	$58
	Prepare and distribute large-scale solution (reanalysis + 3 GCMs)		4	$50
	Gather observational data for evaluation	0.5	2	$33
	Develop software for conversion of simulation results to common file format		1	$13
	Project coordination; interaction w/ sponsor, etc.	4		$67
Total Hub		4.5	7	$221
Each Spoke	Simulate present climate in CA by downscaling reanalysis + 3 GCMs	1	3	$54
Total each Spoke		1	3	$54
Total all spokes		5	15	$271
Total Hub + Spokes		9.5	22	$492

Table 9: Year 1 effort budget

	Task	Effort level senior staff (mos)	Effort Level technical staff (mos)	Est'd Cost (Year 2; $K)
Hub	Evaluate downscaling results vs. observations.	3	16	$250
	Establish project web site.	2	4	$83
	Preparation of peer-reviewed publications	5	3	$121
	Put downscaling results into standard file format.		2	$25
Total Hub		10	25	$479
Spokes	Preparation of peer-reviewed publication	4	2	$92
Total each spoke		4	2	$92
Total all Spokes		20	10	$458
Total Hub + Spokes		**30**	**35**	**$754**

Table 10: Year 2 effort budget

Task	sr staff effort level	sr staff effort cost	tech staff effort level	tech staff effort cost	Total effort cost	hardware cost	Total
Effect of spatial resolution of global climate model	2	$33	4	$50	$83	10	$93
Effect of spatial resolution of regional climate model	2	$33	4	$50	$83	10	$93
Regional vs. global reanalysis	2	$33	4	$67	$100	10	$110
Dynamical vs. statistical downscaling	2	$33	4	$67	$100		$100
Expanded web portal	1	$17	4	$67	$83	30	$113
Total	**9**	**$150**	**20**	**$300**	**$450**	**$60**	**$510**

Table 11: Year 3 effort budget

	Year 1	Year 2	Year 3	Total
Effort at Hub	$221	$479	$225	$925
Effort at all Spokes	$271	$458	$225	$954
Computer access	$35			$35
Data storage	$97		$60	$157
Travel/workshops	$20	$20		$40
Publications		$20		$20
Total	**$203**	**$285**	**$510**	**$2,131**

Table 13: Overall project budget

Project for Probabilistic Projections of Future Climate

Project Scope

This project will be funded independently of the model intercomparison projects described above. In contrast to the above model evaluation projects, which focus on simulating the present climate, the goal of this project will be to make probabilistic projections of future climate in the study area. “Probabilistic projections” means projections that explicitly account for uncertainties in (1) future climate forcings (e.g. greenhouse gas emissions), and (2) uncertainties in scientific understanding of how the climate system will respond to these forcings. In practical terms this means that this project will (1) consider multiple future climate scenarios (i.e. multiple possibilities for future greenhouse gas concentrations and other climate perturbations); and (2) consider results from multiple climate models. As discussed below, an essential part of the project will be the development and application of techniques for estimating uncertainties in future climate (i.e. for making probabilistic projections) based on these multiple projections.

Multiple techniques for making probabilistic climate projections should be investigated. For example, the technique of Bayesian Model Averaging (BMA) has been used with models of surface hydrology; this project will explore its use with climate models. In BMA, a projection is made from results of multiple models by calculating a weighted average; the weights are based on how well each model can reproduce relevant observations. The information needed to obtain these weights will be obtained from the model intercomparison project described above. BMA produces both a mean model result and an associated uncertainty. In addition to using BMA to combine results of multiple models, techniques for estimating uncertainties with respect to parameter values within individual models will be developed and applied. Because of the great computational demands of climate models, uncertainties in the results with respect to values of internal parameters are typically explored minimally, if at all. Yet these uncertainties may be very significant; in addition, more careful optimization of parameter values may allow a much more realistic model solution. Intelligent algorithms for exploring parameter space within individual climate models will be applied and evaluated.

This project will directly leverage the model intercomparison project described above in that it will use “control” (present-climate) simulations from that project (if that project is funded at the Intermediate- or High-Cost level). Effects of increased greenhouse gases and other climate perturbations will be measured in terms of differences between those control simulations and future-climate simulations to be performed under this project.

Project Organization

Like the model intercomparison projects described above, this project will use a Hub and Spoke organization. The Hub is responsible for overall project coordination, data management, data analysis, etc, while the spoke groups perform regional simulations with their individual models or downscaling approaches. Also, as with the model intercomparison projects, the Hub location will provide some computer access to participating downscaling groups.

Specific activities

• Identify future climate scenarios to be considered: These should be from a widely-used source, most likely the IPCC. Tentative choices for forcing scenarios are (1) the IPCC SRES A2, a relatively high emission scenario, with CO2 concentrations increasing monotonically to 850 ppm in 2100; and (2) the IPCC SRES B1, a 550 ppm stabilization scenario, which could serve as a more moderate case. The Hub contractor, in consultation with the sponsor, should be free to reconsider these choices if future developments warrant. (In particular, it my be desirable to use the same scenarios as other, related projects.) It may be desirable, in addition to greenhouse gas and other atmospheric forcings, to consider one scenario including regional land-use change.
• Obtain global model results for future climate scenarios; to be used as the basis for downscaling, global model results with 6-hourly time resolution are needed.
• Prepare GCM results for use as input to RCMs. (Hub)
• Downscale future climate scenarios using multiple RCMs and/or statistical downscaling approaches. (Spokes)
• Combine multiple downscaled solutions into a probabilistic projection using Bayesian Model Averaging. (Hub)
• Investigate climate uncertainties due to uncertainties in parameter values with one RCM. (One selected Spoke, working with Hub)
• Establish project web site making available all model results, documentation, and probabilistic projections (Hub).

	Year 1	Year 2	Year 3
Hub	Obtain, prepare, and distribute large-scale future-climate solutions (2 GCMs, 2 scenarios) Establish project web site	Combine multiple downscaled solutions into a probabilistic projection using Bayesian Model Averaging. Update project web site, making initial project results publicly available	Investigate sensitivities to parameter values w/in one RCM Update project web site to include latest and all project results
Spokes	Downscale 4 future climate simulations (2 GCMs, 2 scenarios)	Put downscaling results into standard file format.	Investigate sensitivities to parameter values w/in one RCM (one Spoke only)

Table 13: Outline of tasks to be performed at Hub and Spoke locations.

	Task	Effort level senior staff (mos)	Effort level technical staff (mos)	Est'd Cost (Year 1; $K)
Hub	Prepare and distribute large-scale solution (2 GCMs, 2 scenarios)		4	$50
	Establish project web site	1	1	$29
	Project coordination; interaction w/ sponsor, etc.	3		$50
Total Hub		4	5	$129
Each Spoke	Downscale 4 future climate scanrios (2 GCMs x 2 scenarios)	1	4	$67
Total each Spoke		1	4	$67
Total all spokes		5	20	$333
Total Hub + Spokes		9	25	$329

Detailed effort budget for Year 1 of the Future Climate Project

	Task	Effort level senior staff (mos)	Effort Level technical staff (mos)	Est’d Cost (Year 2; $K)
Hub	BMA of future climate results	3	12	$200
	Update project web site.	1	3	$54
	Preparation of peer-reviewed publication	4	2	$92
Total Hub		8	17	$346
Spokes	Put downscaling results into standard file format.		2	$25
	Preparation of peer-reviewed publication	1	1	$29
Total each spoke		1	1	$29
Total all Spokes		5	5	$146
Total Hub + Spokes		13	22	$433

Detailed effort budget for Year 2 of the Future Climate Project

	Task	Effort level senior staff (mos)	Effort Level technical staff (mos)	Est’d Cost (Year 2; $K)
Hub	Investigate sensitivitie to RCM parameter values	3	12	$200
	Update project web site.	1	3	$54
	Preparation of peer-reviewed publication	4	2	$92
Total Hub		8	17	$346
Selected Spoke	Investigate sensitivitie to RCM parameter values		2	$25
	Preparation of peer-reviewed publication	1	1	$29
Total selected spoke		1	3	$54
Total Hub + Spokes		9	20	$400

Detailed effort budget for Year 3 of the Future Climate Project

	Year 1	Year 2	Year 3	Total
Effort at Hub	$129	$346	$346	$821
Effort at all Spokes	$333	$146	$54	$533
Computer access	$35			$35
Data storage	$125	$125		$250
Travel/workshops	$20	$20	$20	$60
Publications		$20	$20	$40
Total	$643	$657	$440	$1,739

Overall budget for the Future Climate Project

Summary of Annual Budgets

	Low Cost Intercomparison	Intermediate-Cost Intercomparison	High-Cost Intercomparison	Future Climate Projections
Effort at hub	$272	$492	$925	$821
Effort at Spokes	$88	$417	$954	$533
Computer access	$80	$35	$35	$35
Data storage	$4	$35	$157	$153
Travel/workshops	$40	$40	$40	$60
Publications	$20	$20	$20	$40
Total	**$503**	**$1,038**	**$2,131**	**$1,642**

References:

Denis, B., R. Laprise, D. Caya and J. Côté, 2002: Downscaling ability of one-way nested regional climate models: The Big-Brother Experiment. *Clim. Dyn.* 18:627-646.

Duffy, P.B., W. Arritt, J. Coquard, W. Gutowski, J. Han, J. Iorio, J. Kim, L-R Leung, J. Roads, E. Zeledon, Simulations of present and future climates in the western U.S. with four nested regional climate models, in preparation.

Gershunov, A. and Cayan, D. R., 2003: Heavy daily precipitation frequency over the contiguous United States: Sources of climatic variability and seasonal predictability. *Journal of Climate* 16, 2753–2765.)

Appendix 1: RCM workload, data volume, and disk cost

The table below lists total number of years to be simulated and volumes of data to be produced by RCM simulations for each project option.

	Low	Medium	High	Future
# GCMs to be downscaled	0	2	3	2
# RCMs	3	5	5	5
# Sims per RCM for each GCM	1	2	3	2
Length of each simulation	20	20	30	20
# reanalyses to be downscaled	1	1	1	0
Total # yrs simulated	60	500	1385	400
# RCM grid cells x direction	200	200	200	200
# RCM grid cells y direction	200	200	200	200
# RCM grid cells z direction	20	20	20	20
total #RCM grid cells	800000	800000	800000	800000
# RCM quantities stored	20	20	20	20
how often stored/yr	365	365	365	365
# numbers stored	3.504E+11	2.92E+12	8.0884E+12	2.336E+12
total data volume (Tbyte)	2.8	23.4	64.7	18.7
Disk cost ($K)	$4.2	$35.0	$97.1	$28.0

Estimated data volume from RCM simulations, and cost of associated disk space.

Appendix 2: Bias Corrections and Simulation Evaluation Criteria

Dynamical models of regional climate (i.e. RCMs) require input data that are physically self-consistent. Temperature, pressure, and circulation fields, for example, must all be consistent with governing primitive equations. Thus, for dynamical downscaling, *ad hoc* correction of biases in the driving large-scale fields will lead to spurious results (or worse) in the RCM solution. For statistical downscaling, bias correction is feasible and may be desirable. Whether and how to perform bias corrections will be left to the individual statistical downscaling groups to decide.

Evaluation of downscaled climates will be based primarily on comparison to relevant observation-based data (including reanalyses). Comparison to observations will emphasize meteorological quantities of which observations of good quantity and quality are available, and also quantities having high societal impacts. Near-surface temperature, precipitation, and snow cover are especially important. Evaluation will involve assessment of monthly- and seasonal means, as well as interannual variability, especially response to ENSO.

Appendix 3: List of Acronyms

AMIP	Atmospheric Model Intercomparison Project
BMA	Bayesian Model Averaging
CMIP	Coupled Model Intercomparison Project
DRI	Desert Research Institute
GCM	Global Climate Model (or General Circulation Model)
MIP	Model Intercomparison Project
PNNL	Pacific Northwest National Laboratory
PRUDENCE	Prediction of Regional Scenarios and Uncertainties for Defining European Climate Change Risks and Effects
PMIP	Paleoclimate Modelling Intercomparison Project
RCM	Regional Climate Model
PIRCS	Project for Intercomparison of Regional Climate Simulations
SIO	Scripps Institution of Oceanography (U.C. San Diego)
WRCC	Western Regional Climate Center